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Drop Size Spectra of Foray 48B Produced By A Beecomist Rotary Atomizer

FPM 90-7
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DROP SIZE SPECTRA OF FORAY 48B PRODUCED BY A BEECOMIST ROTARY ATOMIZER

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PREFACE

The purpose of these wind tunnel tests was to establish drop size characteristics of Foray 48B produced by a Beecomist rotary atomizer at flow rates of 0.8 gallons/minute and 1.6 gallons/minute. Results will be used by the USDA Forest Service in developing prescriptions for applying Bacillus thuringiensis and in selecting nozzle types and in positioning nozzles on spray booms. These data will also be used as input to mathematical models which predict spray coverage, canopy penetration, and off-target drift. Wind tunnel tests help to provide data with the aim to achieve optimum droplet spectra and application rates for effective insect control.

Funding was provided by USDA Forest Service, Forest Pest Management, Washington Office. Questions and comments should be directed to the Project Leader, John W. Barry, Forest Pest Management, 2121C Second Street, Davis, CA 95616, (916)758-4600.

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Categorization of Droplets of Foray™ 48B Produced by a Beecomist™ Rotary Atomizer

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Objective

The objective of this study was to determine the atomization characteristics of Novo Laboratories Foray 48B formulation of *Bacillus thuringiensis* under flow rates of 3 liters/minute (0.8 gallons/minute) and 6 liters/minute (1.6 gallons/minute) through a Beecomist rotary atomizer.

Methods and Materials

The material used was Foray 48B, a commercially available product consisting of *Bacillus thuringiensis* Berliner var. *kuristaki* formulated as a flowable concentrate. The product has a potency of 48 billion IU per gallon. All tests were conducted using undiluted product from batch BBN 6000. Material was supplied by Novo Laboratories, Inc. of Danbury, CT.

The *Bt* was pumped to the atomizer by a diaphragm pump connected to a variable speed electric motor. Pump speed was adjusted to supply the required amount of product and reduce bypass from the pressure regulator to a minimum. Flow rates and pressures were calibrated by measuring flow through an orifice plate external to the atomizer. After calibration, the pressure was maintained at the desired value during the testing.

The atomizer used was a Beecomist, an electrically driven rotary device manufactured by Beecomist Systems, Telford, PA. The atomizer was equipped with a medium mesh screen for these tests. The atomizer was powered by direct connection to 24 volt DC batteries. Revolutions per minute were measured by an tachometer internal to the atomizer.

The tests were conducted in a wind tunnel designed and constructed by the University of California, Davis Agricultural Engineering Department to simulate the atomization characteristics of aerial application. Air is drawn through the wind tunnel by the action of a large fan powered by a gasoline engine. Wind speed in the tunnel is measured by a Pitot tube and differential manometer during the tests. Screens are placed over the opening to insure uniform flow and eliminate edge effects in the test section. Test section cross sectional area is 0.37 square meters (4 square feet).

Sampling procedures for rotary atomizers are based upon an area-weighting of a series of point samples. A series of point samples is taken along a radius and used to represent the entire pattern from the center of the pattern to the outside extreme. The pattern is divided into a number of concentric rings and a point sample taken at the area-weighted center of each ring. The data from each point is weighted according to the area of that ring when the distributions from all rings are summed to create the droplet size distribution for the atomizer as a whole.

Data is collected by a Particle Measuring Systems, Inc. (Boulder, CO.) Optical Array Grey Probe Model OAP-2D-GA1 and processed by the Particle Data Processing System 11C. This system uses a Helium-Neon laser beam to create a light source which strikes an array of 64 photodiodes. As a droplet or particle passes through the laser beam, a shadow is created on the photodiode array. Light intensity on each diode is measured at a frequency indicated by the slice rate, and an image of the cross sectional-area of any droplets in the laser beam is constructed at that time. Information about each droplet is analyzed to determine acceptance or rejection based upon such factors as coincidence of multiple droplets and whether or not the entire droplet was within focus and within the laser beam. Also, at least one photodiode must receive full shadow for one interval in order for the droplet to be accepted.

For this work, a slice rate or sampling frequency of 3 megaHertz was used. This translates into a travel distance of 16.4 micrometers between readings for droplets moving at 177 kilometers per hour (110 mph). A droplet of 49 microns could theoretically be sampled three times. In reality, at least two samplings are needed for a droplet to be accepted. This slice rate thus guarantees that droplets of diameter 49 microns or larger will be accepted and has a high probability that droplets of larger than 35 microns will be accurately sampled also. There is a trade-off in sampling frequency. Higher sampling frequencies are desired for the ability to capture small droplets. However, this also increases processing time for the probe, thus meaning that fewer droplets can be measured per time. For these conditions, 3 MHz is a good compromise, allowing us to measure small droplets and still have a high acceptance ratio (approximately 70% to 90%), and still measure enough droplets (on the order of 20,000), to have statistically valid results.

As the PDPS 11C is collecting and processing data about each droplet, it also is counting the number of droplets that pass through the laser beam during that interval. This factor is used by the scaling routines and the averaging routines incorporated into the system software. The averaging routines simply count droplets until a given number (under operator control) of droplets are categorized. At this time, the counts in each category are increased by a factor to account for the number of droplets that could not be simultaneously categorized. This factor represents the fraction of droplets placed into each category during the interval and is used to allocate the count of uncategorized droplets into the various categories in the proper ratio.

As an example, assume the number of droplets to be categorized before this averaging routine was to be executed was set to 100, and those 100 droplets were divided into four categories containing 10, 25, 50 and 15 droplets respectively. The proper ratio is then 0.1 for the first category, 0.25 for the second, 0.5 for the third, and 0.15 for the fourth. If 300 other droplets were noticed during the time required to process the 100 droplets, the distribution would be credited with 40 droplets on the first category (10 measured + 0.10 x 300 noticed), 100 in the second (25 + 0.25 x 300), 200 in the third (50 + 0.50 x 300), and 60 in the fourth category (15 + 0.15 x 300). This scaling is done internally by hardware and software in the sampling equipment.

Data generated by the PDPS 11C is then transferred electronically to an Epson PX-8 battery powered microcomputer. The Epson PX-8 does a preliminary analysis of the data and can print a simple report on site. The total number of particles imaged is collected at this time by a separate circuit built by the Agricultural Engineering Department and used to compare the ratio of accepted to imaged droplets. This is an indicator of both density of the cloud and ability of the equipment to image a cloud of that density with the parameters chosen for that test. Values of 60% acceptance or larger are desired.

From the Epson PX-8, the data is transferred electronically to an IBM AT microcomputer where more complete analysis occurs. Data is processed in the IBM AT and tables and charts as found in the Appendices are produced. Statistical parameters are calculated in the IBM AT also. Specific definitions of the values listed in the Appendices are explained and detailed in Appendix A.

Physical Properties

Measurements of some of the physical properties of Foray 48B, batch BBN 6000 were made in the Agricultural Engineering Department chemical laboratory. The results are presented in Table 1, for the properties of density, surface tension, and viscosity. All three properties were measured over the temperature range of 5°C to 25°C at 5°C intervals.

Density was measured by use of a pycnometer, which had previously been calibrated over the temperature range using distilled water. Samples of Foray were heated or cooled in a water bath as required.

Surface tension measurements were taken using a Fisher Surface Tensiomat Model 21 torsion balance tensiometer. This instrument was also calibrated for each of the temperatures to be used by using distilled water prior to analyzing Foray 48B.

Viscosity measurements were taken with a Brookfield Synchro-Lectric viscometer. Initial tests were done to roughly characterize the material over the temperature range of interest. The data collection was conducted with instrument settings which allowed a constant sampling procedure over the range. The material is non-Newtonian, meaning that viscosity is a function of shear rate as well as temperature, thus this step was necessary to develop meaningful comparisons between the measurements taken across the temperature range.

All viscosity measurements reported here were taken at a shear rate of 75/sec and with material that had been continually stirred by a magnetic stir bar for 24 hours prior to taking the measurements. This was done to simulate the processes of transport, loading, and ferrying that would occur under field conditions. The magnetic stir bar is relatively gentle, thus time was set to 24 hours. A study of time versus viscosity at one temperature showed that after 20 minutes, the product apparently reached a fully agitated state, as viscosity did not change appreciably when time of stirring was increased from 20 minutes to 30 minutes.

A study of surface tension changes with continuous stirring was also conducted. No significant change in surface tension was found associated with stirring.

Table 1. Density, surface tension, and viscosity of Foray 48B as a function of temperature.

Temperature °C	Density g/cm^3	Surface Tension dynes/cm	Viscosity centipoise
5.	1.176	52.2	163.5
10.	1.177	53.2	133.5
15.	1.176	52.0	117.7
20.	1.174	51.4	107.4
25.	1.171	53.1	97.0

Results and Discussion

All tests were conducted with five rings per atomizer. Three replicates were conducted for each sample ring and combined into three distinct replicate measurements of the distribution of the entire pattern. The three replicates were than averaged to determine the summary statistics described here.

The detailed droplet size distributions are shown in Appendix C for the 3 liters/minute (0.8 gallons/minute) flow rate and Appendix D for 6 liters/minute (1.6 gallons/minute) flow rate. The averages for three replicates are shown first, followed by the information for each individual replicate.

The following Table summarizes the results. All tests were done using undiluted Foray 48B, at an airstream speed of 177 kilometers per hour (110 miles per hour), and a rotational speed of 10,000 revolutions per minute. Droplet diameters are all given in micrometers unless otherwise stated.

Table 4. Summary Statistics for Droplet Size Distributions.

Statistic	3.0 lpm (0.8 gpm)	6.0 lpm (1.6 gpm)
Volume Median Diameter, $D_{V.5}$	248.	279.
Number Median Diameter, $D_{N.5}$	98.	83.
$D_{V.1}$	151.	163.
$D_{V.9}$	364.	385.
Relative Span	0.86	0.80
$D_{N.1}$	<56.	<56.
$D_{N.9}$	236.	253.
Number Mean Diameter, D_{10}	118.	116.
Volume Mean Diameter, D_{30}	165.	172.
Sauter Mean Diameter, D_{32}	220.	240.

The effects on the distribution most notable for the increase in smaller droplets found with the increase in flow rate. The total number of droplets categorized increased by 3.67 million with the increase in flow rate. This increase consisted of an increase of 5.13 million droplets of size smaller than 89 microns, a decrease of 3.56 million in droplets found with diameters between 89 microns and 252 microns in diameter, and an increase, by 2.1 million, of droplets larger than 252 microns and smaller than 611 microns. There was no change in the overall width of the distribution.

Figure 1 is a graphical presentation of cumulative mass fraction versus droplet diameter for both conditions. They coincide at both extremes and have approximately the same slope over the entire range. There is some spread near the middle of the distributions, with the lower flow rate reaching 50% of the mass at a size that is nearly 30 microns smaller than that for the high flow rate.

Figure 2 represents the cumulative volume less than the stated droplet diameter for the two conditions tested. The most significant increase in the volume when the flow rate increases, can be seen to occur in the droplets of 200 microns diameter and larger. If the size range of the most biologically efficacious droplets is known, this information can be useful in deciding whether to use two atomizers in place of one and reduce the flow rate per atomizer by one half.

There is a difference in the shape of the mass or volume distribution between these two flow rates. On a plot of mass or volume frequency versus droplet diameter, as found in page C.2 and D.2, the 3 liters per minute (lpm) rate has a relatively rapid increase in the mass frequency to a peak in the seventh category, those droplets with a diameter between 220 and 252 microns. From this size category, the distribution decreases in frequency gradually to its upper extreme at the size category with an upper limit of 611 microns. The 1.6 lpm distribution on the same scales, shows a contrast with a more gradual increase, to a peak mass frequency in the ninth size category, which includes droplets from 318 to 351 microns diameter. This distribution then decreases more rapidly than the 0.8 lpm flow rate distribution to its upper limit, again at the category with an upper limit of 611 microns.

The droplets size distributions emitted by this atomizer under these two conditions are similar. The doubling of liquid flow rate increases the volume median diameter by approximately 30 microns, from 248 to 279 microns. One can conclude that the atomizer is not overloaded at these flow rates of this product. Energy available for droplet formation, either from rotational energy of the atomizer or from the passing airstream, is sufficient to atomize the additional product without major changes in the emitted droplet size spectrum.

Figure 1. Cumulative mass or volume function for the droplet size distribution as emitted by a Beecomist rotary atomizer at 10,000 rpm in a 177 kilometer per hour (110 mph) airstream when atomizing undiluted NOVO BioKontrol Foray 48B at two flow rates.

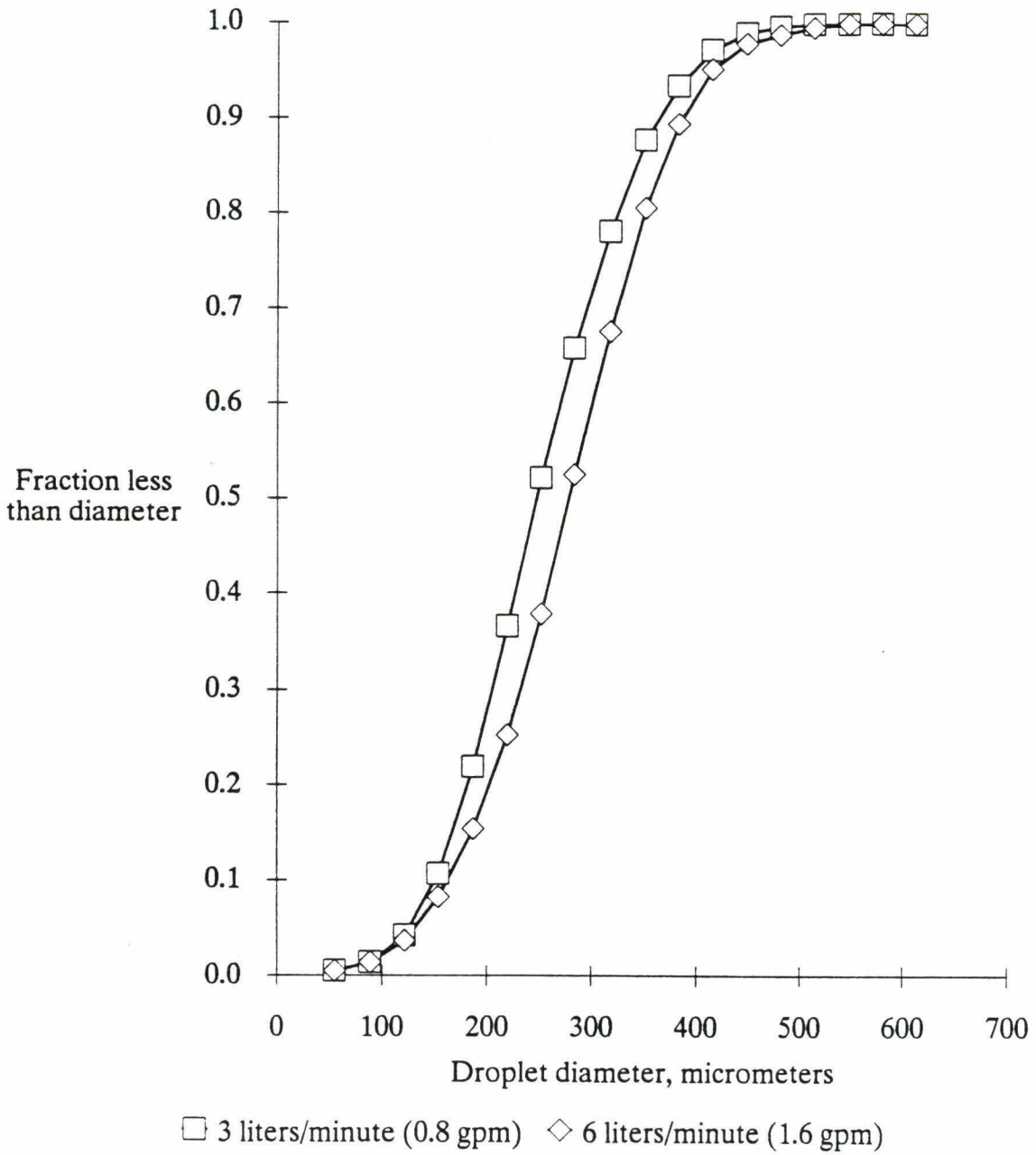
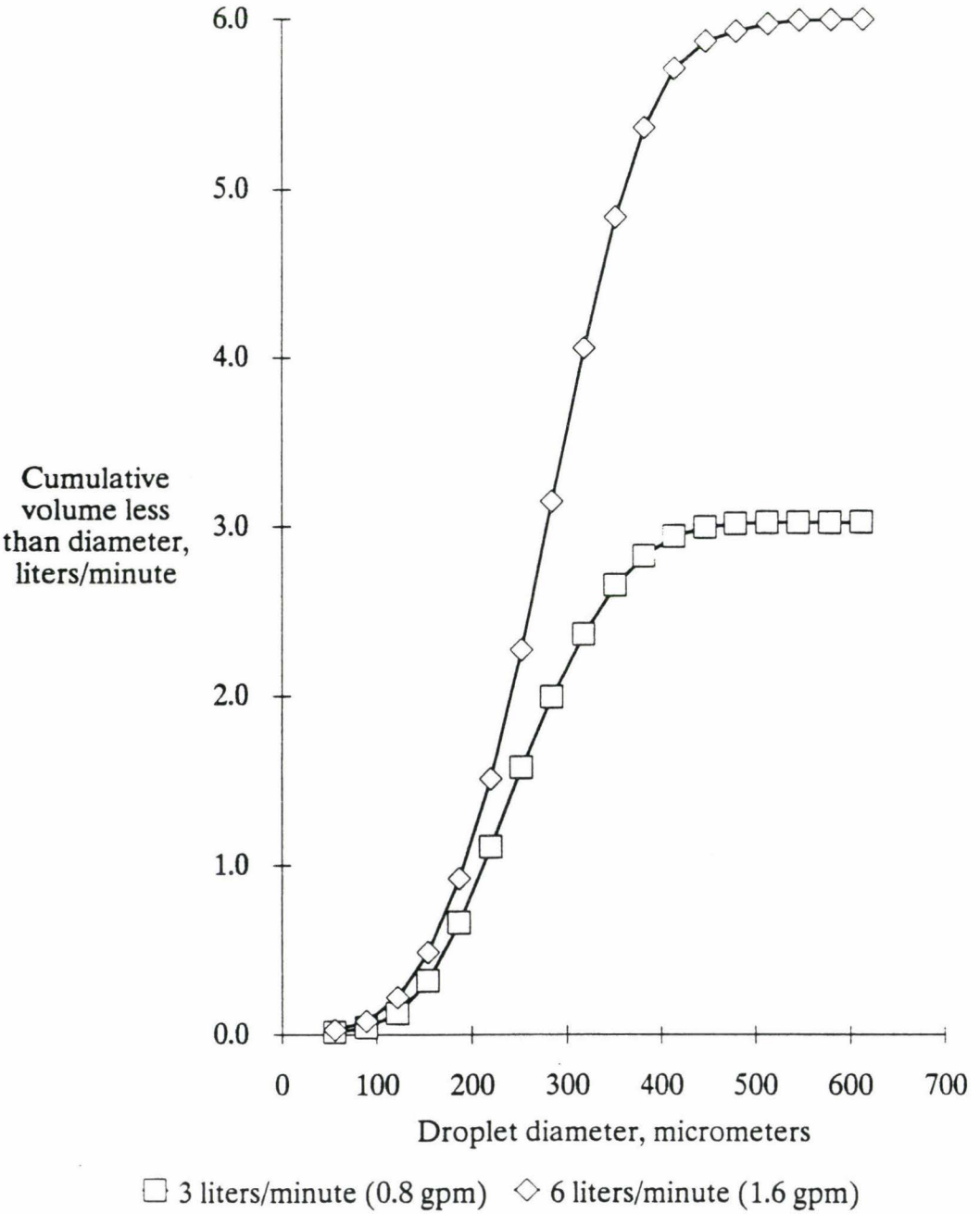


Figure 2. Cumulative volume less than stated droplet diameter as emitted by a Beecomist atomizer operating at 10,000 rpm in a 177 kilometer per hour (110 mph) airsteam when atomizing undiluted NOVO BioKontrol Foray 48B at two flow rates.



Appendix A. Definitions of Terms as found on Tables and Figures in Appendices and Results and Discussion

Nozzle	Atomizer under study.
Angle to Airstream	Angle between centerline of atomizer and direction of airflow. (0 degrees = coincident, 90 degrees = perpendicular with centerline of atomizer pointing vertically downward, 180 degrees = opposite)
Spray Pressure	Pressure on the liquid at the atomizer.
Airspeed	Mean speed of the air moving through the wind tunnel.
Flow Rate	Liquid flow rate through the atomizer.
Tank Mix	The liquid being atomized.
Slice Rate	Frequency of sampling by the droplet categorization system.
AVG	The number of droplets to categorize between executions of the averaging routine by the droplet categorization system. This is done to scale measured droplets according to the density of the spray cloud during the time required to measure each droplet.
DFM	Depth of Field (Mechanical). The physical length of the laser beam exposed to the spray cloud.
BAR	Bulk Area Ratio. The limit set by the droplet categorization system for acceptance of a droplet. Bulk area ratio is the ratio of length x width of the image of a droplet to the projected area of the same droplet as computed by the formula Pi x r squared. Images with a BAR above the noted value are rejected.
Distance to Probe	The physical distance between two parallel planes, one passing through the average emission point of the atomizer and the other passing through the centerline of the laser beam exposed to the spray cloud.
Sample Interval	An internal setting of the droplet categorization equipment for the frequency of a forced execution of the averaging routines.
Number of Samples	The number of sample intervals used for the entire data collection period. Total time of data collection equals number of samples x sample interval.
Number of Sample Rings	Used only for rotary atomizers. This is the number of concentric rings, each represented by a point sample, which comprise the pattern produced by the atomizer.

Number of Scans	For a hydraulic nozzle, the distribution is collected by moving the nozzle in a rectangular pattern, starting in one corner of a rectangle which encloses the entire emitted pattern. The nozzle moves alternately up or down so that the liquid spray cloud passes by the probe. The number of scans is the number of times the nozzle is moved up or down in constructing the entire pattern. (See scan spacing and scan length.)
Scan Spacing	The distance between successive vertical scans of the pattern. The test begins at one side of the pattern and moves by an interval equal to scan spacing between vertical scans until the other side of the pattern is reached.
Scan Length	The length of each of the vertical scans.
File	The name of the file containing the data for each test. This file name is used in the UCD Agricultural Engineering Department IBM AT which is used for the data analysis.
Number of Tests Combined	Under some circumstances, more than one test is used to represent the distribution from an atomizer. The additional tests can either be summed (if each represents only a portion of the entire pattern), or averaged.
Upper Limit	The diameter in micrometers of the upper limit of each of the droplet size categories. Each category is 33 microns in width. This value is determined by the hardware and optics of the unit.
N(Raw)	The number of droplets measured by the system that fell within that category.
N/sec	The number of droplets in that category passing the sample point per second during the test. This uses the scaled counts obtained using the procedure explained under AVG above.
Gm/sec	Mass represented by the N/second column assuming spherical droplets of unit density.
% N	The percentage of the total number of droplets (N/sec) in the entire distribution which fall into this category.
% Vol	Percentage of the volume of the distribution contained in droplets within this category.
Accumulated % N	Sum of the % N column for this category and all categories smaller.
Accumulated % Vol.	Sum of the % Volume column for this category and all categories smaller.

Total Accepted Raw Particles	Number of all droplets that were measured and were accepted by the system.
Total Images	All droplets measured. Includes those rejected because they were out of focus or not contained entirely within the laser beam.
Representative Statistics	The following statistics conform to ASTM notation for summary statistics of a droplet or particle size distribution. In the following formula, N_i is the number of droplets in the category i, and D_i is a representative diameter of the category. For all categories, the representative diameter was taken to be a droplet of average volume for the category.

The general formula is $D_{(pq)} = (\text{Sum } (N_i)^*(D_i \hat{} p))/(\text{Sum}(N_i)^*(D_i \hat{} q))$

Number Mean Diameter	Average diameter of all droplets in the distribution.
Volume Mean Diameter	Average volume of all droplets in the distribution.
Sauter Mean Diameter	A droplet with the same ratio of surface area to mass as the distribution as a whole.
$D_{N.x}$	Diameter of a drop where 0.x fraction of the total number of droplets in the distribution which are smaller than this droplet.
$D_{N.5}$	Number median diameter. Also called count median diameter. Half of the total number of droplets are smaller than this diameter and the other half are larger than this diameter.
$D_{V.x}$	Diameter of a drop where 0.x fraction of the total volume of the distribution is found in droplets which are smaller than this droplet.
$D_{V.5}$	Volume median diameter. Also called mass median diameter. Half of the total volume of the distribution is found in droplets smaller than this diameter and the other half of the volume is in droplets larger than this diameter.
Relative Span	$(D_{V.9}-D_{V.1})/D_{V.5}$

Appendix B. Sample Ring Data

All rings are concentric and aligned on the centerline of the atomizer. For these tests, a total of 2000 cm^2 was represented in the sampling procedure.

Ring No.	Area cm^2	Inner Edge cm	Outer Edge cm
1	200.	0.00	7.98
2	300.	7.98	12.62
3	500.	12.62	17.84
4	500.	17.84	21.85
5	500.	21.85	25.23

Appendix C. Flow Rate of 0.8 gallons/minute (3 liters/minute)

C.3 Summary table from the average of three tests.

C.4 Graphical representation of the average distribution from three tests.

C.5 Summary table from replicate 1.

C.6 Graphical presentation of results from replicate 1.

C.7 Summary table from replicate 2.

C.8 Graphical presentation of results from replicate 2.

C.9 Summary table from replicate 3.

C.10 Graphical presentation of results from replicate 3.

Nozzle	Beecomist	Slice Rate	3 MHz
RPM	10000	AVG	100
Spray Pressure	20 psi	DFM	1 cm.
Airspeed	110 mph	BAR	1.5
Flow Rate	.8 gpm	Distance to Probe	90 cm.
Tank Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
FILE: C:\PMS\DATA\04189000.000		Number of Sample Rings	5
Blade Angle	0 degrees		

Number of Tests Combined: 1

UPPER LIMIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.
56	1053	2.19E+07	0.72	35.92	0.50	35.92	0.50
89	2704	6.82E+06	1.36	11.20	0.94	47.12	1.44
122	2973	6.62E+06	4.02	10.89	2.80	58.01	4.24
154	2414	6.73E+06	9.21	11.06	6.41	69.07	10.65
187	1744	6.24E+06	16.14	10.25	11.23	79.32	21.88
220	1299	4.84E+06	21.15	7.95	14.72	87.27	36.61
252	1040	3.28E+06	22.35	5.39	15.56	92.66	52.17
284	831	1.96E+06	19.69	3.22	13.71	95.88	65.87
318	716	1.22E+06	17.57	2.01	12.23	97.89	78.11
351	521	709174	13.87	1.17	9.65	99.06	87.76
382	291	321867	8.22	0.53	5.72	99.59	93.48
414	154	164586	5.42	0.27	3.77	99.86	97.25
447	59	60680	2.53	0.10	1.76	99.96	99.01
479	24	17593	0.91	0.03	0.63	99.99	99.65
512	11	6198	0.39	0.01	0.27	100.00	99.92
545	1	322	0.02	0.00	0.02	100.00	99.94
578	1	152	0.01	0.00	0.01	100.00	99.95
611	1	682	0.07	0.00	0.05	100.00	100.00
TOTAL	1.58E+04	6.08E+07	143.67				

TOTAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 15835/ 23346.34 = 67.8%

NUMBER MEAN DIA.= D_{10}.... 117.60 µm
VOLUME MEAN DIA.= D_{30}.... 165.29 µm
SAUTER MEAN DIA.= D_{32}.... 219.69 µm

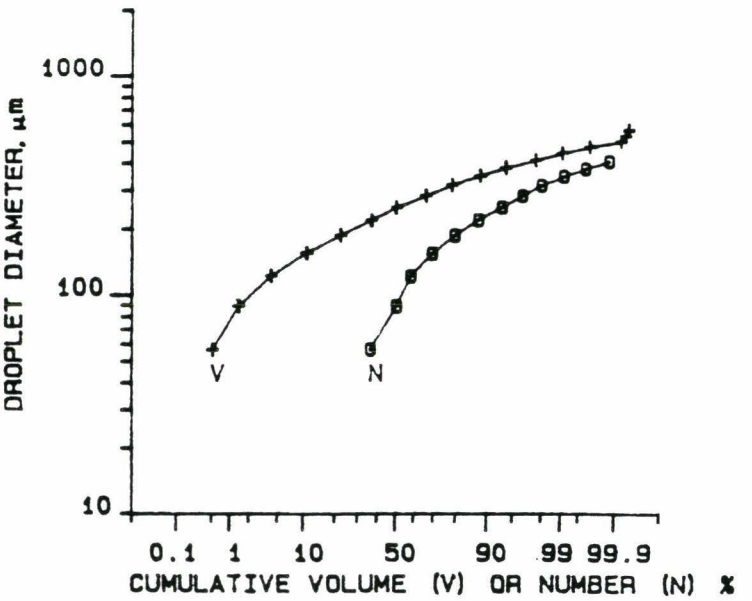
NUMBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 97.66 µm
$D_{N.9}$... 236.21 µm

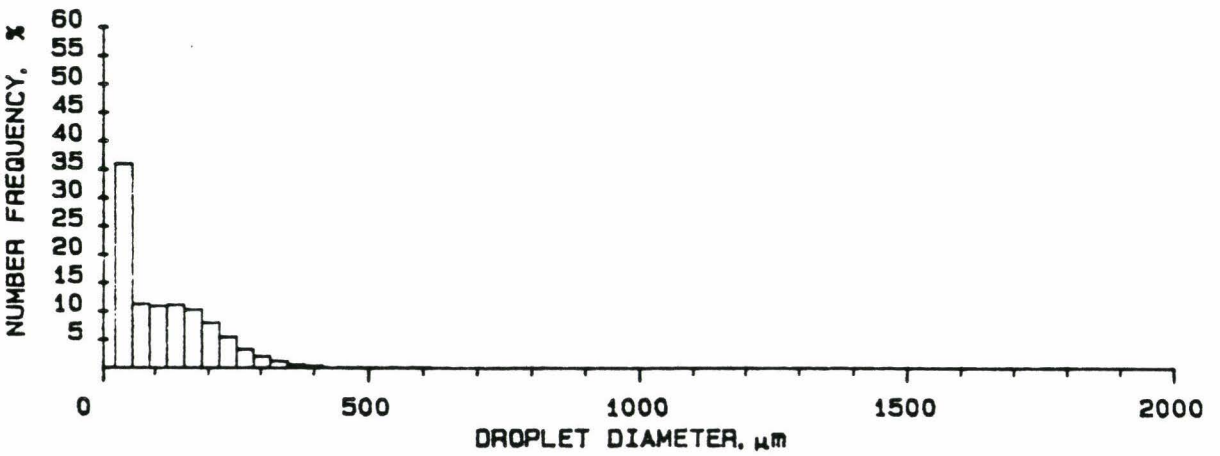
VOLUME MEDIAN DIA.= $D_{V.1}$... 151.24 µm
$D_{V.5}$... 247.90 µm
$D_{V.9}$... 363.83 µm

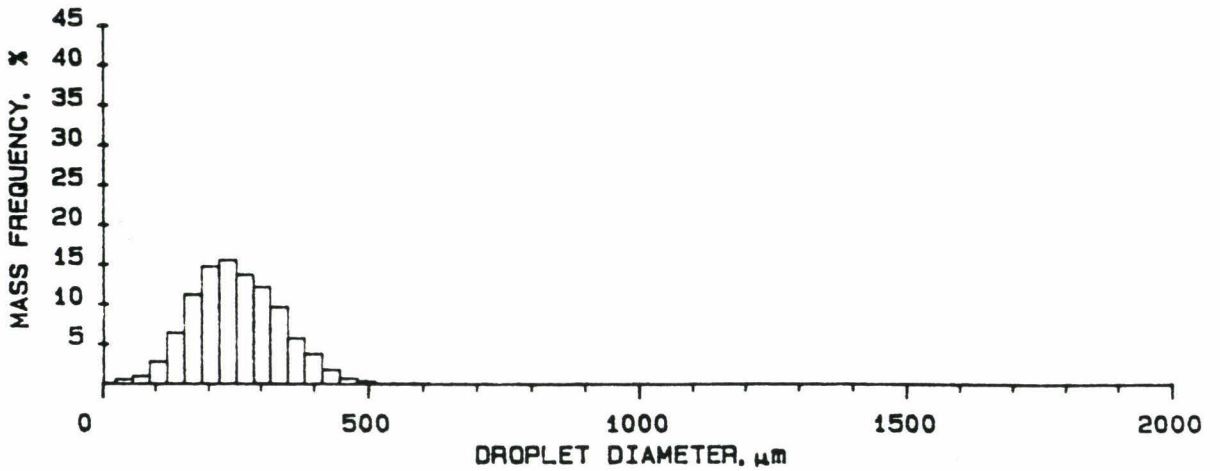
RELATIVE SPAN= 0.86

Nozzle Type . . . BEECOMIST
RPM 0
Blade Angle . . . 0 degrees
Spray Pressure . . 20 psi
Airspeed . . . . . 110 mph
Flow Rate 8
Tank Mix: Foray 48B

FILE: C:\PMS\DATA\04189000.000







replicate 1

Nozzle	BEECOMIST	Slice Rate	3 MHz
RPM	10000	AVG	100
Spray Pressure	30 psi	DFM	1 cm.
Airspeed	110 mph	BAR	1.5
Flow Rate	.8 gpm	Distance to Probe	90 cm.
Tank Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
FILE: C:\PMS\DATA\04189010.000		Number of Sample Rings	5

Number of Tests Combined: 5

UPPER LIMIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.
56	1122	2.76E+07	0.91	36.39	0.52	36.39	0.52
89	2803	7.55E+06	1.50	9.97	0.86	46.36	1.38
122	3337	8.09E+06	4.91	10.68	2.82	57.04	4.20
154	2936	8.76E+06	11.99	11.57	6.88	68.61	11.09
187	2110	8.10E+06	20.97	10.70	12.04	79.31	23.13
220	1683	6.38E+06	27.90	8.42	16.02	87.73	39.15
252	1286	4.17E+06	28.44	5.51	16.33	93.24	55.48
284	926	2.30E+06	23.10	3.04	13.26	96.28	68.75
318	676	1.39E+06	20.00	1.84	11.49	98.12	80.24
351	479	841209	16.45	1.11	9.45	99.23	89.68
382	264	326555	8.34	0.43	4.79	99.66	94.47
414	128	174681	5.75	0.23	3.30	99.89	97.78
447	44	57642	2.40	0.08	1.38	99.97	99.16
479	26	18965	0.98	0.03	0.56	99.99	99.72
512	6	5125	0.33	0.01	0.19	100.00	99.91
545	3	575	0.04	0.00	0.03	100.00	99.93
578	0	0	0.00	0.00	0.00	100.00	99.93
611	1	806	0.09	0.00	0.05	100.00	99.98
644	0	0	0.00	0.00	0.00	100.00	99.98
677	1	188	0.03	0.00	0.02	100.00	100.00
TOTAL	1.78E+04	7.57E+07	174.12				

TOTAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 17831/ 24705 = 72.2%

NUMBER MEAN DIA.= D_{10}.... 117.54 µm
VOLUME MEAN DIA.= D_{30}.... 163.83 µm
SAUTER MEAN DIA.= D_{32}.... 215.98 µm

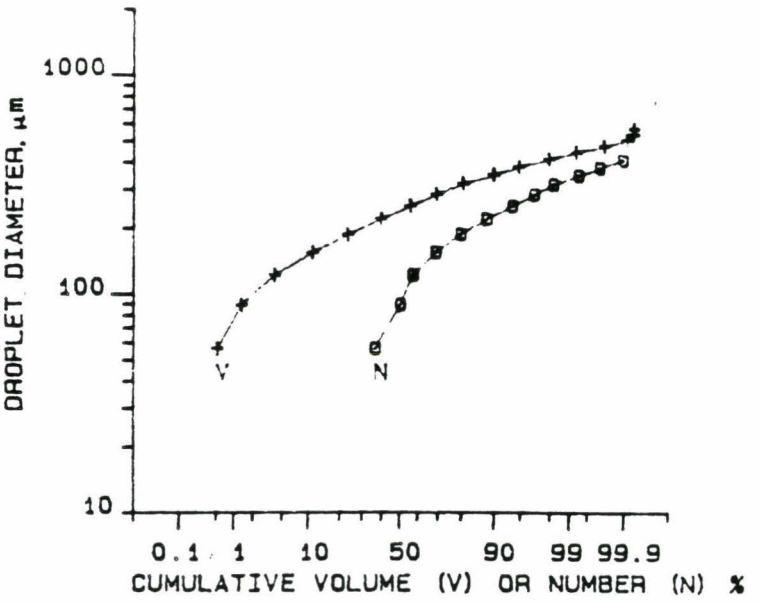
NUMBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 100.19 µm
$D_{N.9}$... 233.09 µm

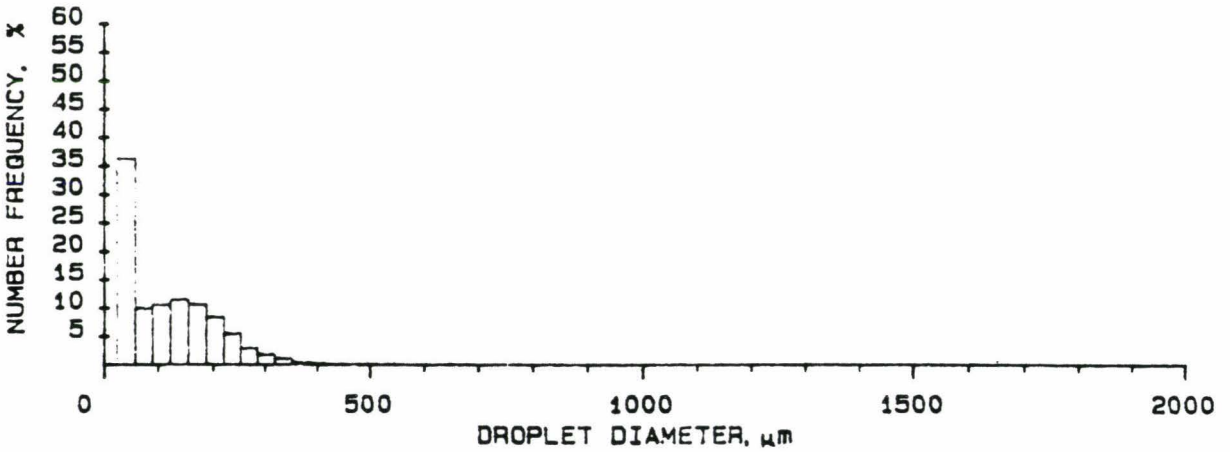
VOLUME MEDIAN DIA.= $D_{V.1}$... 149.40 µm
$D_{V.5}$... 241.42 µm
$D_{V.9}$... 353.07 µm

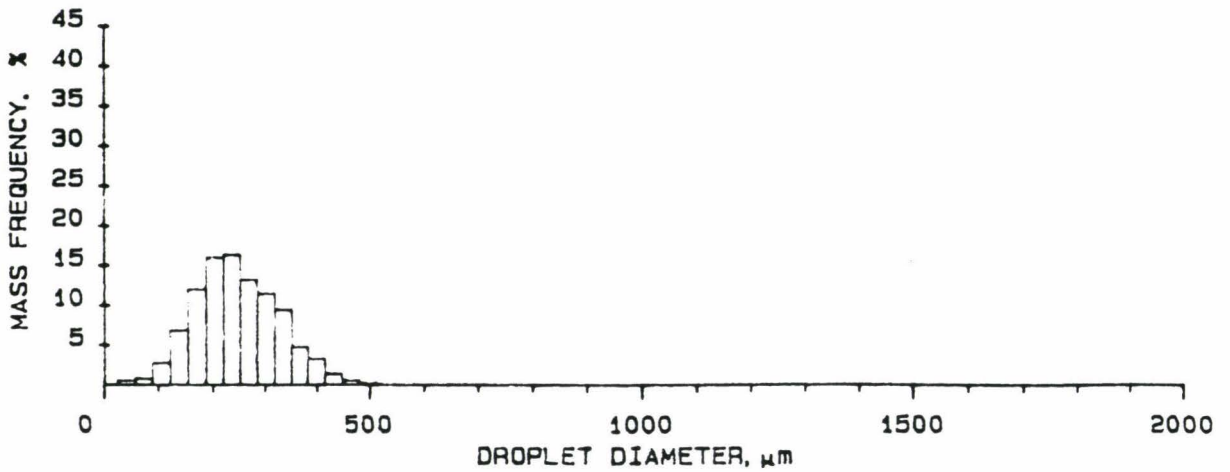
RELATIVE SPAN= 0.84

Nozzle Type . . . BEECOMIST
RPM 10000
Spray Pressure . . 30 psi
Airspeed . . . . . 110 mph
Flow Rate 8
Tank Mix: Foray 48B

FILE: C: \PMS\DATA\04189010.000







replicate 2

Nozzle	BEECOMIST	Slice Rate	3 MHz
RPM	10000	AVG	100
Spray Pressure	20 psi	DFM	1 cm.
Airspeed	110 mph	BAR	1.5
Flow Rate	.8 gpm	Distance to Probe	90 cm.
Tank Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
FILE: C:\PMS\DATA\04189010.300		Number of Sample Rings	5

Number of Tests Combined: 5

UPPER LIMIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.
56	893	1.49E+07	0.49	35.84	0.41	35.84	0.41
89	2304	4.89E+06	0.97	11.80	0.81	47.64	1.22
122	2310	4.06E+06	2.47	9.81	2.05	57.45	3.27
154	1458	3.33E+06	4.56	8.04	3.79	65.49	7.06
187	1085	3.80E+06	9.83	9.17	8.18	74.66	15.25
220	907	3.57E+06	15.62	8.61	13.00	83.27	28.25
252	769	2.56E+06	17.43	6.17	14.51	89.44	42.76
284	729	1.92E+06	19.32	4.64	16.08	94.08	58.83
318	699	1.13E+06	16.27	2.73	13.54	96.81	72.37
351	546	663579	12.98	1.60	10.80	98.41	83.17
382	321	372593	9.51	0.90	7.92	99.31	91.09
414	187	183024	6.03	0.44	5.02	99.75	96.11
447	61	73833	3.08	0.18	2.56	99.93	98.67
479	26	19600	1.02	0.05	0.85	99.98	99.52
512	18	8859	0.56	0.02	0.47	100.00	99.98
545	0	0	0.00	0.00	0.00	100.00	99.98
578	1	209	0.02	0.00	0.02	100.00	100.00
TOTAL	1.23E+04	4.14E+07	120.14				

TOTAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 12314/ 19257 = 63.9%

NUMBER MEAN DIA.= D_{10}.... 123.97 µm
VOLUME MEAN DIA.= D_{30}.... 176.97 µm
SAUTER MEAN DIA.= D_{32}.... 236.73 µm

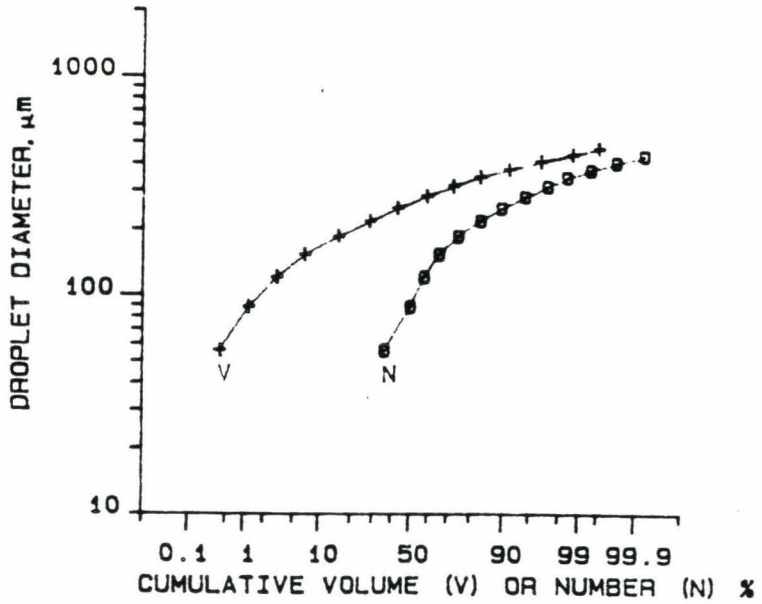
NUMBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 96.87 µm
$D_{N.9}$... 255.78 µm

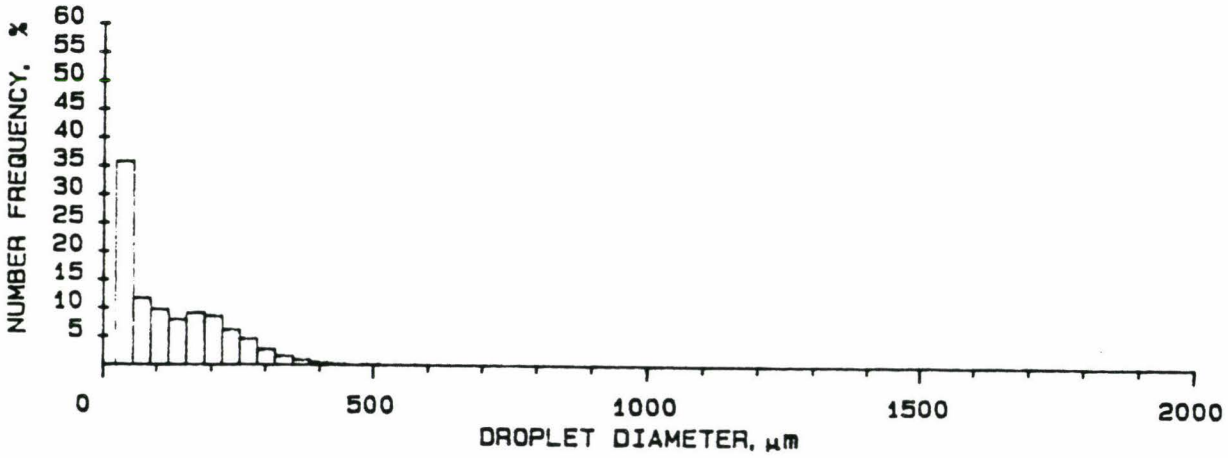
VOLUME MEDIAN DIA.= $D_{V.1}$... 166.14 µm
$D_{V.5}$... 266.67 µm
$D_{V.9}$... 379.34 µm

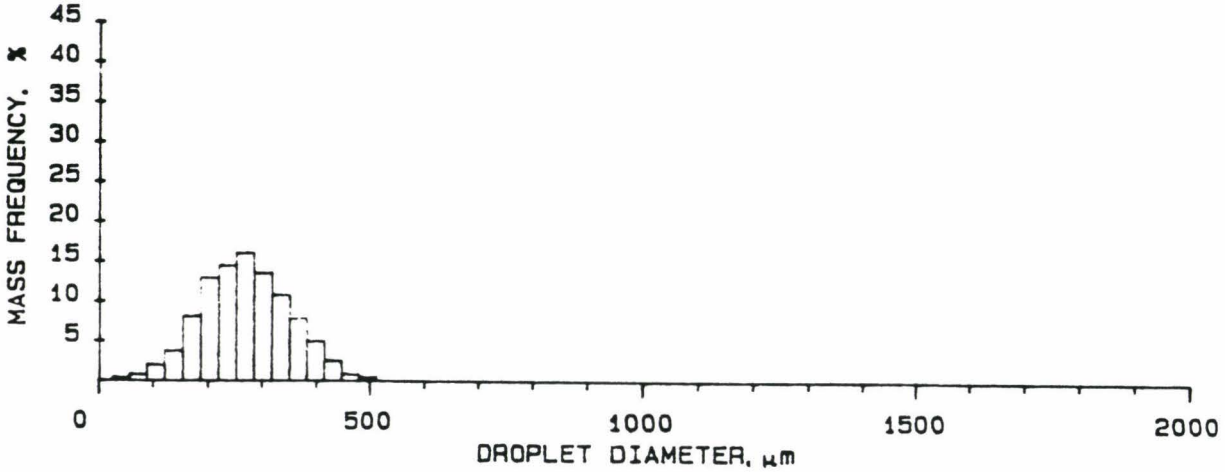
RELATIVE SPAN= 0.80

Nozzle Type . . . BEECOMIST
RPM 10000
Spray Pressure . . 20 psi
Airspeed . . . . . 110 mph
Flow Rate 8
Tank Mix: Foray 48B

FILE: C: \PMS\DATA\04189010.300







replicate 3

zzle	BEECOMIST	Slice Rate	3 MHz
M	10000	AVG	100
ray Pressure	20 psi	DFM	1 cm.
rspeed	110 mph	BAR	1.5
ow Rate	.8 gpm	Distance to Probe	90 cm.
nk Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
LE: C:\PMS\DATA\04189012.000		Number of Sample Rings	5

mber of Tests Combined: 5

PER MIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.	
56	1143	2.31E+07	0.76	35.42	0.56	35.42	0.56	N) %
89	3006	8.01E+06	1.59	12.25	1.16	47.68	1.72	
22	3272	7.72E+06	4.68	11.81	3.43	59.48	5.15	
54	2847	8.10E+06	11.09	12.40	8.11	71.88	13.25	
87	2036	6.80E+06	17.61	10.41	12.87	82.30	26.13	
20	1307	4.56E+06	19.95	6.98	14.59	89.27	40.71	
52	1064	3.11E+06	21.18	4.76	15.49	94.03	56.20	
84	837	1.66E+06	16.67	2.54	12.19	96.57	68.39	
18	773	1.14E+06	16.44	1.75	12.02	98.32	80.41	
51	537	622734	12.18	0.95	8.91	99.27	89.32	
82	289	266454	6.80	0.41	4.98	99.68	94.29	
14	146	136053	4.48	0.21	3.28	99.89	97.57	
47	72	50565	2.11	0.08	1.54	99.97	99.11	
79	21	14216	0.74	0.02	0.54	99.99	99.65	
12	9	4611	0.29	0.01	0.21	100.00	99.86	
45	1	391	0.03	0.00	0.02	100.00	99.88	
78	1	247	0.02	0.00	0.02	100.00	99.90	0
11	1	1240	0.14	0.00	0.10	100.00	100.00	
TAL	1.74E+04	6.53E+07	136.76					

TAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 17362/ 26077 = 66.6%

MBER MEAN DIA.= D_{10}.... 113.64 µm
LUME MEAN DIA.= D_{30}.... 158.77 µm
UTER MEAN DIA.= D_{32}.... 210.99 µm

MBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 95.43 µm
$D_{N.9}$... 224.53 µm

LUME MEDIAN DIA.= $D_{V.1}$... 141.36 µm
$D_{V.5}$... 239.29 µm
$D_{V.9}$... 355.43 µm)0

LATIVE SPAN= 0.89

Appendix D. Flow Rate of 1.6 gallons/minute (6 liters/minute)

D.3 Summary table from the average of three tests.

D.4 Graphical representation of the average distribution from three tests.

D.5 Summary table from replicate 1.

D.6 Graphical presentation of results from replicate 1.

D.7 Summary table from replicate 2.

D.8 Graphical presentation of results from replicate 2.

D.9 Summary table from replicate 3.

D.10 Graphical presentation of results from replicate 3.

Nozzle	Beecomist	Slice Rate	3 MHz
RPM	10000	AVG	100
Spray Pressure	36 psi	DFM	1 cm.
Airspeed	110 mph	BAR	1.5
Flow Rate	1.6 gpm	Distance to Probe	90 cm.
Tank Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
FILE: C:\PMS\DATA\04189000.500		Number of Sample Rings	5
Blade Angle	0 degrees		
Number of Tests Combined: 1			

UPPER LIMIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.
56	1236	2.61E+07	0.86	40.45	0.50	40.45	0.50
89	2842	7.75E+06	1.54	12.00	0.89	52.45	1.39
122	2883	6.56E+06	3.98	10.15	2.30	62.61	3.69
154	2256	5.69E+06	7.79	8.81	4.50	71.41	8.20
187	1706	4.80E+06	12.43	7.44	7.19	78.85	15.39
220	1331	3.89E+06	17.03	6.03	9.85	84.88	25.24
252	1183	3.21E+06	21.87	4.97	12.65	89.85	37.89
284	1053	2.53E+06	25.38	3.91	14.68	93.76	52.57
318	851	1.81E+06	26.06	2.81	15.07	96.56	67.64
351	616	1.15E+06	22.40	1.77	12.96	98.34	80.60
382	340	598888	15.29	0.93	8.85	99.26	89.45
414	189	304295	10.02	0.47	5.80	99.74	95.25
447	81	110416	4.60	0.17	2.66	99.91	97.91
479	28	31481	1.63	0.05	0.94	99.96	98.85
512	12	19145	1.22	0.03	0.70	99.99	99.56
545	3	8232	0.63	0.01	0.37	100.00	99.92
578	2	872	0.08	0.00	0.05	100.00	99.97
611	1	472	0.05	0.00	0.03	100.00	100.00
TOTAL	1.66E+04	6.46E+07	172.86				

TOTAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 16614/ 17616.67 = 94.3%

NUMBER MEAN DIA.= D_{10}.... 115.51 µm
VOLUME MEAN DIA.= D_{30}.... 172.32 µm
SAUTER MEAN DIA.= D_{32}.... 239.99 µm

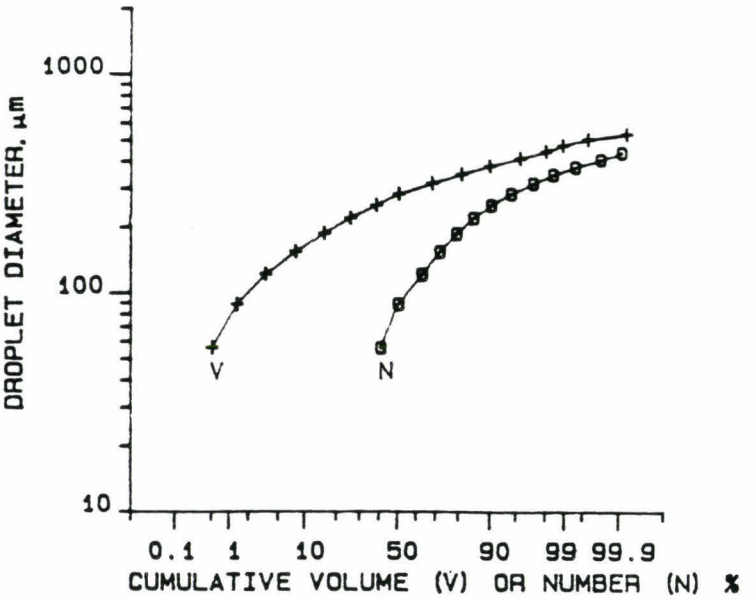
NUMBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 82.53 µm
$D_{N.9}$... 253.10 µm

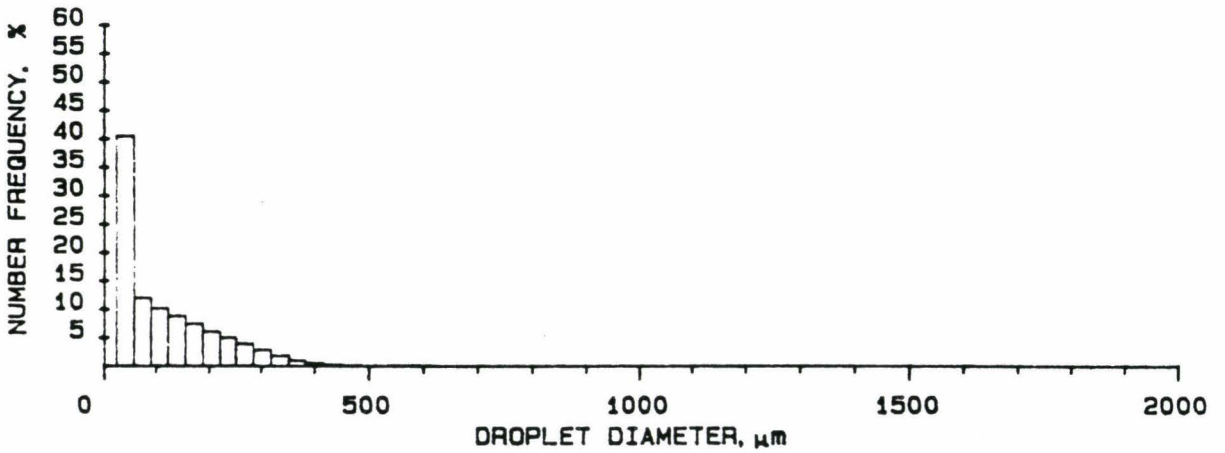
VOLUME MEDIAN DIA.= $D_{V.1}$... 162.58 µm
$D_{V.5}$... 279.02 µm
$D_{V.9}$... 385.12 µm

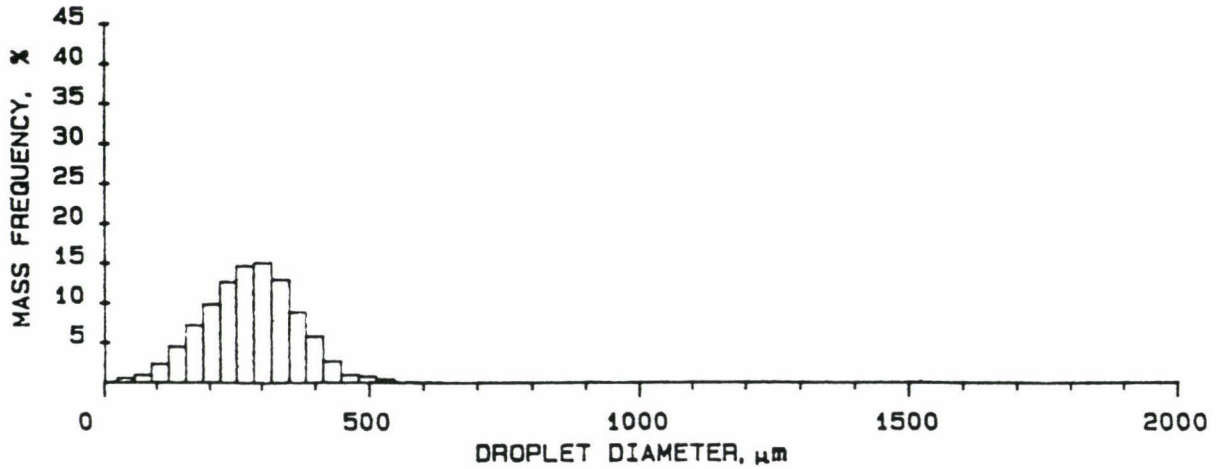
RELATIVE SPAN= 0.80

Nozzle Type . . . Beecomist
RPM 10000
Blade Angle . . . 0 degrees
Spray Pressure . . 36 psi
Airspeed . . . . . 110 mph
Flow Rate 1.6
Tank Mix: Foray 48B

FILE: C: \PMS\DATA\04189000.500







replicate 1

Nozzle	BEECOMIST	Slice Rate	3 MHz
RPM	10000	AVG	100
Spray Pressure	36 psi	DFM	1 cm.
Airspeed	110 mph	BAR	1.5
Flow Rate	1.6 gpm	Distance to Probe	90 cm.
Tank Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
FILE: C:\PMS\DATA\04239012.500		Number of Sample Rings	5

Number of Tests Combined: 5

UPPER LIMIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.
56	1104	2.10E+07	0.69	38.57	0.46	38.57	0.46
89	2714	6.75E+06	1.34	12.39	0.89	50.95	1.34
122	2847	6.01E+06	3.65	11.03	2.41	61.98	3.75
154	2141	5.14E+06	7.03	9.43	4.64	71.41	8.39
187	1569	4.05E+06	10.48	7.43	6.91	78.84	15.30
220	1245	3.17E+06	13.89	5.82	9.16	84.66	24.46
252	1120	2.58E+06	17.55	4.73	11.58	89.39	36.03
284	1008	2.15E+06	21.60	3.94	14.25	93.33	50.28
318	855	1.62E+06	23.36	2.98	15.40	96.31	65.68
351	577	990964	19.38	1.82	12.78	98.13	78.46
382	335	545549	13.93	1.00	9.19	99.13	87.65
414	184	258941	8.53	0.47	5.62	99.61	93.27
447	96	140022	5.83	0.26	3.85	99.86	97.12
479	39	43644	2.26	0.08	1.49	99.94	98.61
512	19	24197	1.54	0.04	1.01	99.99	99.63
545	3	7241	0.56	0.01	0.37	100.00	99.99
578	1	94	0.01	0.00	0.01	100.00	100.00
TOTAL	1.59E+04	5.45E+07	151.64				

TOTAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 15857/ 15135 =104.8%

NUMBER MEAN DIA.= D_{10}.... 117.44 µm
VOLUME MEAN DIA.= D_{30}.... 174.55 µm
SAUTER MEAN DIA.= D_{32}.... 242.85 µm

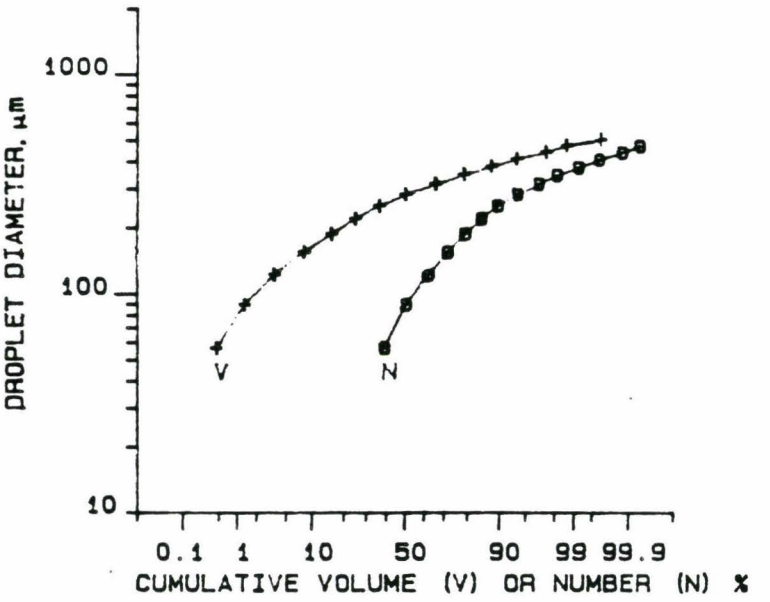
NUMBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 86.74 µm
$D_{N.9}$... 256.93 µm

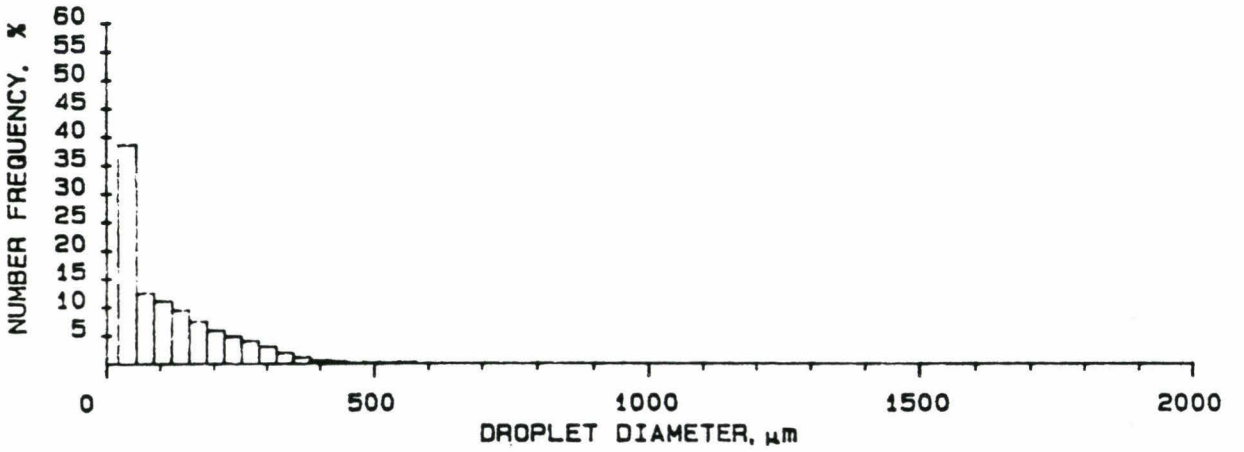
VOLUME MEDIAN DIA.= $D_{V.1}$... 162.00 µm
$D_{V.5}$... 284.16 µm
$D_{V.9}$... 395.79 µm

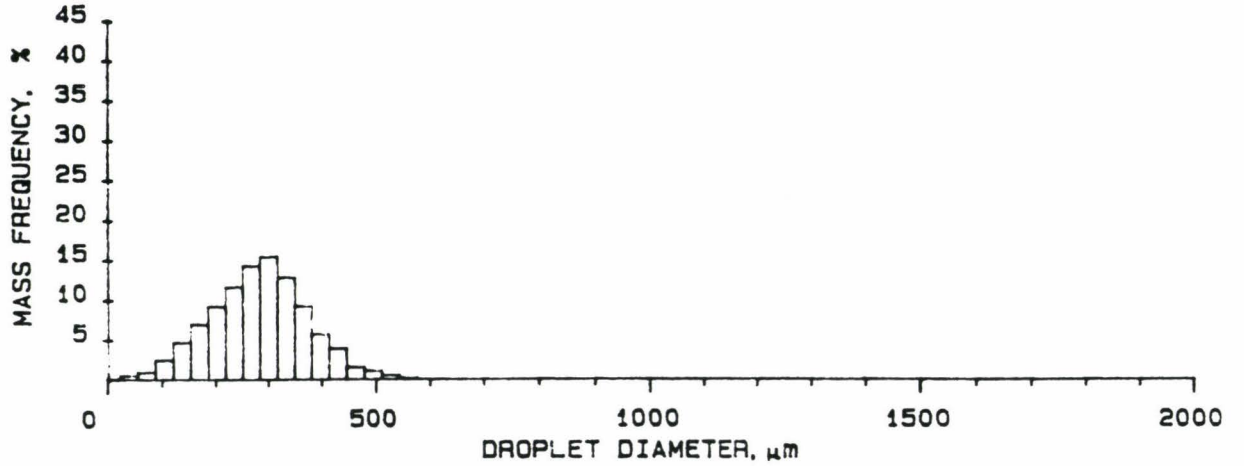
RELATIVE SPAN= 0.82

Nozzle Type . . . BEECOMIST
RPM 10000
Spray Pressure . . 36 psi
Airspeed . . . . . 110 mph
Flow Rate 1.6
Tank Mix: Foray 48B

FILE: C:\PMS\DATA\04239012.500







replicate 2

Nozzle	BEECOMIST	Slice Rate	3 MHz
RPM	10000	AVG	100
Spray Pressure	36 psi	DFM	1 cm.
Airspeed	110 mph	BAR	1.5
Flow Rate	1.6 gpm	Distance to Probe	90 cm.
Tank Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
FILE: C:\PMS\DATA\04189013.000		Number of Sample Rings	5

Number of Tests Combined: 5

UPPER LIMIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.
56	1315	2.65E+07	0.87	40.54	0.49	40.54	0.49
89	2889	7.74E+06	1.54	11.84	0.87	52.38	1.37
122	2818	6.35E+06	3.86	9.72	2.18	62.10	3.55
154	2294	5.70E+06	7.80	8.72	4.42	70.82	7.97
187	1791	5.01E+06	12.97	7.67	7.35	78.49	15.32
220	1395	4.08E+06	17.86	6.25	10.12	84.74	25.43
252	1254	3.37E+06	22.93	5.15	12.99	89.89	38.42
284	1104	2.52E+06	25.36	3.86	14.36	93.75	52.78
318	928	1.88E+06	26.96	2.87	15.27	96.62	68.05
351	699	1.16E+06	22.66	1.77	12.83	98.39	80.88
382	383	574369	14.67	0.88	8.31	99.27	89.18
414	215	280452	9.23	0.43	5.23	99.70	94.41
447	104	122763	5.12	0.19	2.90	99.89	97.31
479	34	30585	1.59	0.05	0.90	99.93	98.21
512	13	23580	1.50	0.04	0.85	99.97	99.06
545	5	17241	1.33	0.03	0.75	99.99	99.81
578	3	2001	0.18	0.00	0.10	100.00	99.91
611	2	1417	0.16	0.00	0.09	100.00	100.00
TOTAL	1.72E+04	6.54E+07	176.58				

TOTAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 17246/ 20795 = 82.9%

NUMBER MEAN DIA.= D_{10}.... 116.02 µm
VOLUME MEAN DIA.= D_{30}.... 172.86 µm
SAUTER MEAN DIA.= D_{32}.... 240.36 µm

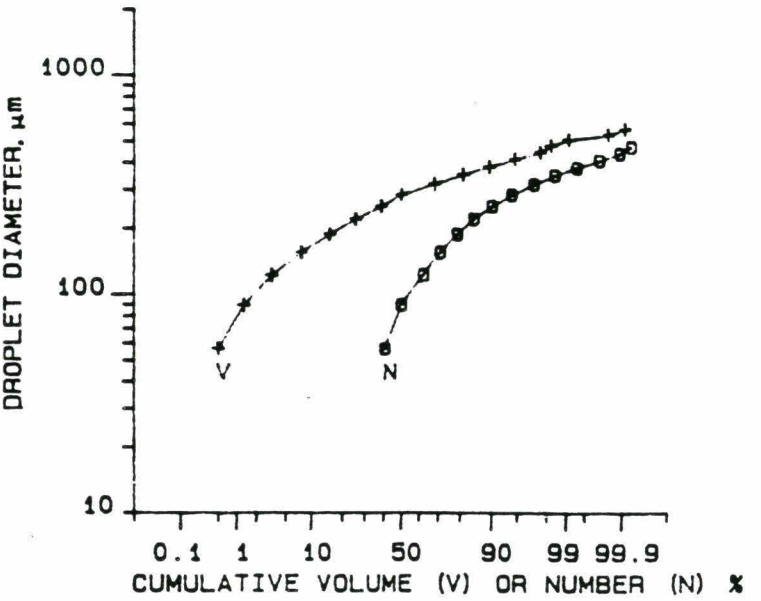
NUMBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 82.63 µm
$D_{N.9}$... 252.76 µm

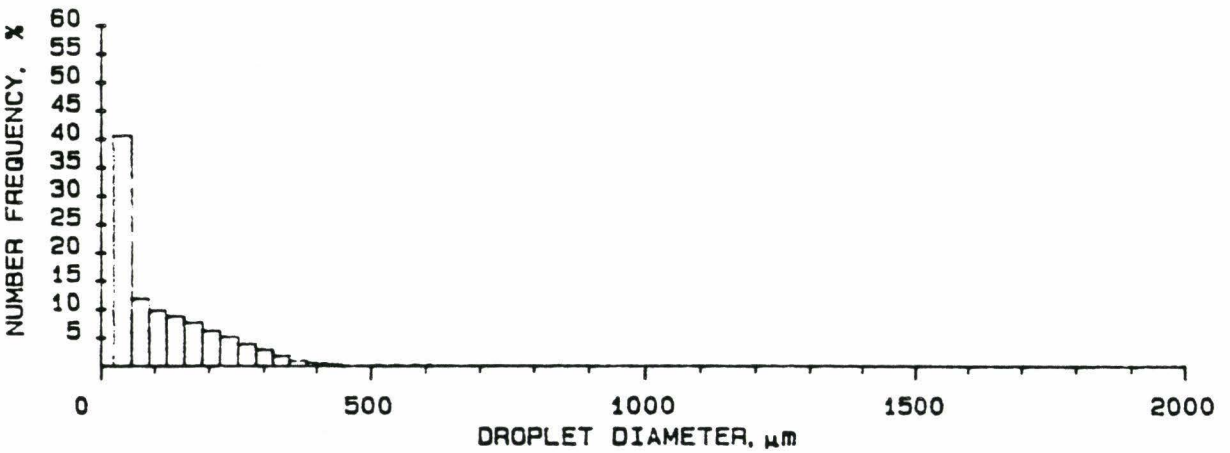
VOLUME MEDIAN DIA.= $D_{V.1}$... 163.42 µm
$D_{V.5}$... 278.42 µm
$D_{V.9}$... 387.15 µm

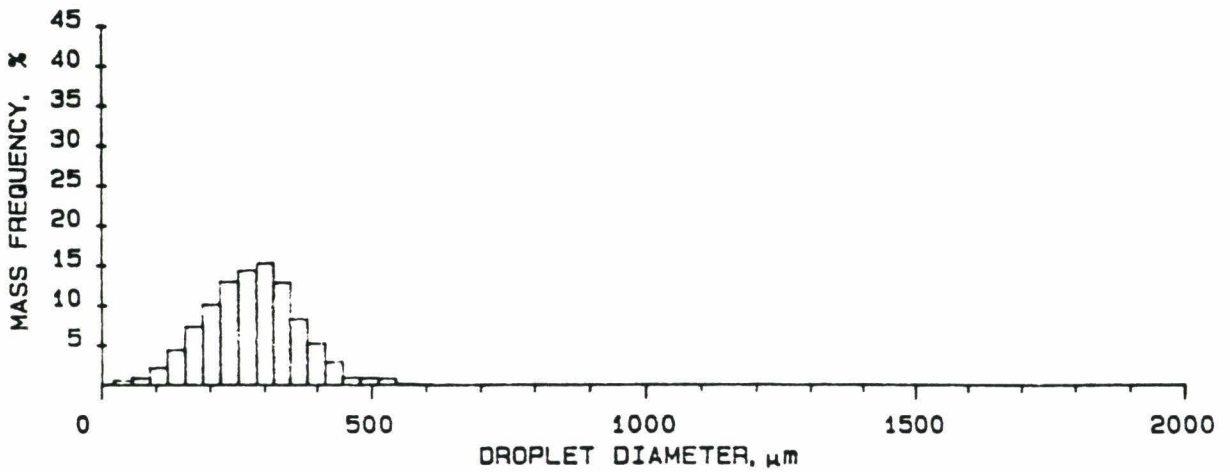
RELATIVE SPAN= 0.80

Nozzle Type . . . BEECOMIST
RPM 10000
Spray Pressure . . 36 psi
Airspeed . . . . . 110 mph
Flow Rate 1.6
Tank Mix: Foray 48B

FILE: C:\PMS\DATA\04189013.000







replicate 3

Nozzle	BEECOMIST	Slice Rate	3 MHz
RPM	10000	AVG	100
Spray Pressure	36 psi	DFM	1 cm.
Airspeed	110 mph	BAR	1.5
Flow Rate	1.6 gpm	Distance to Probe	90 cm.
Tank Mix	Foray 48B	Sample Interval	1 sec.
		Number of Samples	60
FILE: C:\PMS\DATA\04189013.200		Number of Sample Rings	5

Number of Tests Combined: 5

UPPER LIMIT	N(RAW)	N/SEC	Gm/SEC	% N	% VOL.	ACCUMULATED % N	ACCUMULATED % VOL.
56	1289	3.09E+07	1.02	41.77	0.53	41.77	0.53
89	2922	8.76E+06	1.74	11.85	0.91	53.62	1.45
122	2983	7.31E+06	4.44	9.89	2.33	63.51	3.78
154	2333	6.23E+06	8.52	8.43	4.48	71.94	8.26
187	1759	5.35E+06	13.84	7.24	7.27	79.18	15.52
220	1354	4.42E+06	19.34	5.98	10.16	85.16	25.69
252	1174	3.69E+06	25.11	4.99	13.19	90.15	38.88
284	1048	2.90E+06	29.17	3.93	15.32	94.08	54.20
318	769	1.94E+06	27.85	2.62	14.63	96.70	68.83
351	573	1.29E+06	25.17	1.74	13.22	98.44	82.06
382	303	676746	17.28	0.92	9.08	99.36	91.13
414	167	373492	12.30	0.51	6.46	99.87	97.59
447	44	68463	2.85	0.09	1.50	99.96	99.09
479	12	20213	1.05	0.03	0.55	99.99	99.64
512	5	9659	0.61	0.01	0.32	100.00	99.97
545	1	215	0.02	0.00	0.01	100.00	99.97
578	2	522	0.05	0.00	0.03	100.00	100.00
TOTAL	1.67E+04	7.39E+07	190.35				

TOTAL ACCEPTED RAW PARTICLES / TOTAL IMAGES = 16738/ 16920 = 98.9%

NUMBER MEAN DIA.= D_{10}.... 113.64 µm
VOLUME MEAN DIA.= D_{30}.... 170.15 µm
SAUTER MEAN DIA.= D_{32}.... 237.42 µm

NUMBER MEDIAN DIA.= $D_{N.1}$... <56 µm
$D_{N.5}$... 79.18 µm
$D_{N.9}$... 251.51 µm

VOLUME MEDIAN DIA.= $D_{V.1}$... 162.22 µm
$D_{V.5}$... 275.75 µm
$D_{V.9}$... 379.78 µm

RELATIVE SPAN= 0.79

Nozzle Type . . . BEECOMIST
RPM 10000
Spray Pressure . . 36 psi
Airspeed . . . . . 110 mph
Flow Rate 1.6
Tank Mix: Foray 48B

FILE: C: \PMS\DATA\04189013.200